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Weather systems associated with some occasions of severe turbulence in clear air at high altitude: a further analysis

by

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Summary

This paper is an extension of work carried out by Bannon (1,2) and largely confirms the results which he found.

A further 147 reports of severe turbulence encountered in clear air at altitudes between 15,000 and 48,000 ft. over or near the British Isles were analysed in relation to broad features of the 300 mb. contour chart. Seventy-one per cent of the occasions were associated with a jet stream, nine per cent were not associated with any particular feature of the charts and nearly all the remaining twenty per cent were associated with upper lows, upper troughs or strong winds. The occurrences near jet streams were again found to be grouped mainly on the low pressure side of the jet and to a lesser extent above the axis on the anticyclonic side. Less than ten per cent were found to be below the jet axis on the high pressure side.

The highest level at which severe turbulence was encountered was 48,000 feet.

1. Introduction. In previous papers (1,2) attempts have been made to correlate the occurrence of severe turbulence with various meteorological situations and it was found that the large majority was in the vicinity of jet streams.

This paper describes a further analysis of all reports of turbulence encountered between 15,000 and 48,000 ft. and which were described as "severe" or "very severe" during the period August, 1951, and February, 1953. It was considered that reports of a lesser severity, (that is "moderate", "slight", "perceptible", etc.) were not of any great importance in an investigation of this sort and therefore only the "severe" cases were taken into consideration.

2. Method of reporting. All the reports of turbulence received were qualitative assessments because none of the aircraft participating in this investigation carried an accelerometer. Most of the reports were received from operational Royal Air Force jet bombers and fighters but some were also received from Royal Navy and Civil aircraft.

Since all the reports are qualitative it is difficult to be certain whether all pilots adopted the same standard of severity when reporting. There is always the risk that a pilot may describe an occurrence as severe because he considered it severe compared with the usual turbulence at high levels and not on an absolute scale. In order to try to overcome this possible human error and in an endeavour to achieve consistency and uniformity, the following statement was included on all forms used for entering reports on incidents of turbulence:

"The following may serve as a rough guide in the assessment of the turbulence encountered:-

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(a) Perceptible (± .05g to ± .2g) - Perceptible difference from steady flying conditions.

(b) Moderate (± .2g to ± .5g) - Uncomfortable, slight tendency to be lifted out of seat.

(c) Severe (± .5g upwards) - Difficulty in observing flying instruments and/or maintenance of aircraft heading. Marked tendency to be thrown from seat."

Some of the incidents reported were unusually severe and two examples are given below:-

(a) "Aircraft (Meteor) was pitching and tossing about the sky and one of its instruments was shaken from the instrument panel."

(b) "Crew were lifted from their seats. Aircraft (Canberra) suffered structural damage and several rivets were dislodged."

Other reports described the turbulence as "moderate to severe" and "mainly moderate but occasionally severe" etc. but for the purpose of this analysis were regarded as "severe".

In all, 147 reports obtained during the period August, 1951, to February, 1953 were studied. The true airspeed of the aircraft at the time when the turbulence was encountered varied between about 250 and 450 knots.

3. Method of analysis. Each report was studied in conjuction with the information given in the Daily Aerological Record and an attempt was made to associate the turbulence with broad features of the relevant 300mb. contour chart, that is, with jet streams, strong winds, lows, troughs and discontinuity in the tropopause surface. A summary of the cases occurring in various weather situations is given in Table I below.

Table I

Weather situations associated with occasions of severe turbulence in clear air at high altitude

Weather Situation	No. of Cases
Near jet stream	98
Probably near jet stream (i.e. jet stream present but details of maximum wind speed, height of jet etc. not available)	7
Upper trough	19
Upper low	3
Discontinuity in tropopause surface at same level as turbulence and within 100 miles of it.	1
As above and near upper trough	2
As above and near upper low	0
Strong upper winds but no evidence of a well defined jet stream	4
Unclassified	13
Total	147

The thirteen unclassified cases occurred in situations that could not be classed as any one of the above types. A few of them were in the middle of upper ridges and there was no vertical or horizontal wind shear, nor a discontinuity of any kind that could be detected.

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Of the 147 cases, 21 occurred in the stratosphere, two were almost at the tropopause level and the remainder were in the upper troposphere.

As regards the height at which the severe turbulence was encountered, the majority of cases were between 25,000 and 35,000 ft., 25 between 35,000 and 40,000 ft., 7 between 40,000 and 45,000 ft. and one was above 45,000ft. The latter was experienced in a Canberra over Leicester on 19th October, 1951, between 47,500 and 48,000 ft. It occurred near an upper trough and about 10,000 feet above the tropopause.

It is not safe to conclude from the above figures that the incidence is less in the lower stratosphere because in all probability the amount of flying at those levels was considerably less than at those below 40,000 ft.

4. Jet Streams. The reports of severe turbulence in the vicinity of jet streams were further analysed with regard to their position relative to the axis of the jet. The method used was the same as that employed in previous work (1,2). By inspection of the 300 mb. charts and the wind reports given in the Daily Aerological Record the position, orientation and height of the axis of the jet were estimated at the time the turbulence was reported. For this purpose it was assumed that the jet stream was defined by more or less straight and parallel contours with a maximum wind speed of 80 knots or more, and the contour gradient decreasing on both sides of the maximum.

The level of the jet stream was taken as the level of the maximum wind reported on the upper air soundings in the vicinity of the jet. This wind report was taken as the nearest approximation to the maximum speed of the jet.

When a report of turbulence did not coincide with the time of routine upper air soundings an allowance was made for movement of the jet axis by using continuity considerations of space and time.

As in previous work (1,2) the horizontal unit of measurement was taken as the distance from the centre of the jet stream, on the low pressure side, over which the wind velocity at the same level as the axis of the jet fell to half the maximum value. The vertical co-ordinate was taken as the difference between the I.C.A.N. pressure equivalent of the height and the pressure at the axis of the jet.

This method of analysis has the following disadvantages:-

(a) The jet axis cannot be positioned very accurately but on the other hand the direction of the jet must be reasonably accurate on most occasions.

(b) The height of the jet axis need not necessarily be the same as the height of the wind maximum observed at a point near the jet but, in general, the difference should be small. Bearing in mind that in the normal jet stream the isopleths of wind speed are relatively close together in the quadrants below the axis on the low pressure side and above the axis on the high pressure side, it follows that the height of the axis was probably underestimated for soundings on the low pressure side and overestimated for those on the high pressure side.

(c) An analysis of this kind must be subjective to a certain extent.

It is claimed, however, in view of the fairly large number of cases examined that the accuracy obtained is sufficient to show the main features, although there may be some uncertainty in any particular case. As already indicated in Table I 98 cases were deemed to have been near jet streams. A further 7 cases were probably within the sphere of influence of a jet stream but there were not enough data available to make a satisfactory assessment of the position, height and maximum wind at the axis of the jet.

The co-ordinates thus obtained for the positions of the reports with respect to the jet stream were plotted in Figs. 1 and 2 which show all the cases examined for the periods August, 1951, to August, 1952 and September, 1952 to February, 1953 respectively. Details regarding certain parameters of the jet streams are given in Table II below.

/Table II

Table II

Mean values and extremes of various parameters of jet streams in which 98 severe turbulence incidents were reported

	Wind Speed at the axis (knots)	Pressure at the axis (mb.)	Horizontal scale (n. mi.)
August, 1951 to August, 1952			
Mean	115	283	147
Extremes	80 (minimum) 170 (maximum)	-	50 (minimum) 300 (maximum)
September, 1952 to February, 1953			
Mean	122	315	162
Extremes	87 (minimum) 165 (maximum)	-	70 (minimum) 360 (maximum)

The horizontal unit is the distance from the axis, at the same level on the low pressure side, at which the wind speed is half the value at the axis.

As in the previous analysis the most striking result is that severe turbulence was encountered on less than ten per cent of occasions in the quadrant below and on the high pressure side of the axis, and 75 per cent were in the two quadrants on the low pressure side.

An attempt was made to study any variations with respect to position along the jet stream. But only three cases occurred near the entrance and eleven near the exit of a jet and these numbers are too small for any particular significance to be attached to them.

5. Conclusions. This analysis of occasions of severe turbulence occurring over and near the British Isles in clear air at high levels confirms a previous finding that the major number occur in association with well defined jet streams and that most of the others were associated with upper lows, upper troughs or strong winds. About nine per cent appeared to have no obvious association with any pattern in the upper air. 75 per cent of the cases reported near jet streams were on the low pressure side of the jet. Of the remaining 25 per cent (on the high pressure side) less than ten per cent were below the axis.

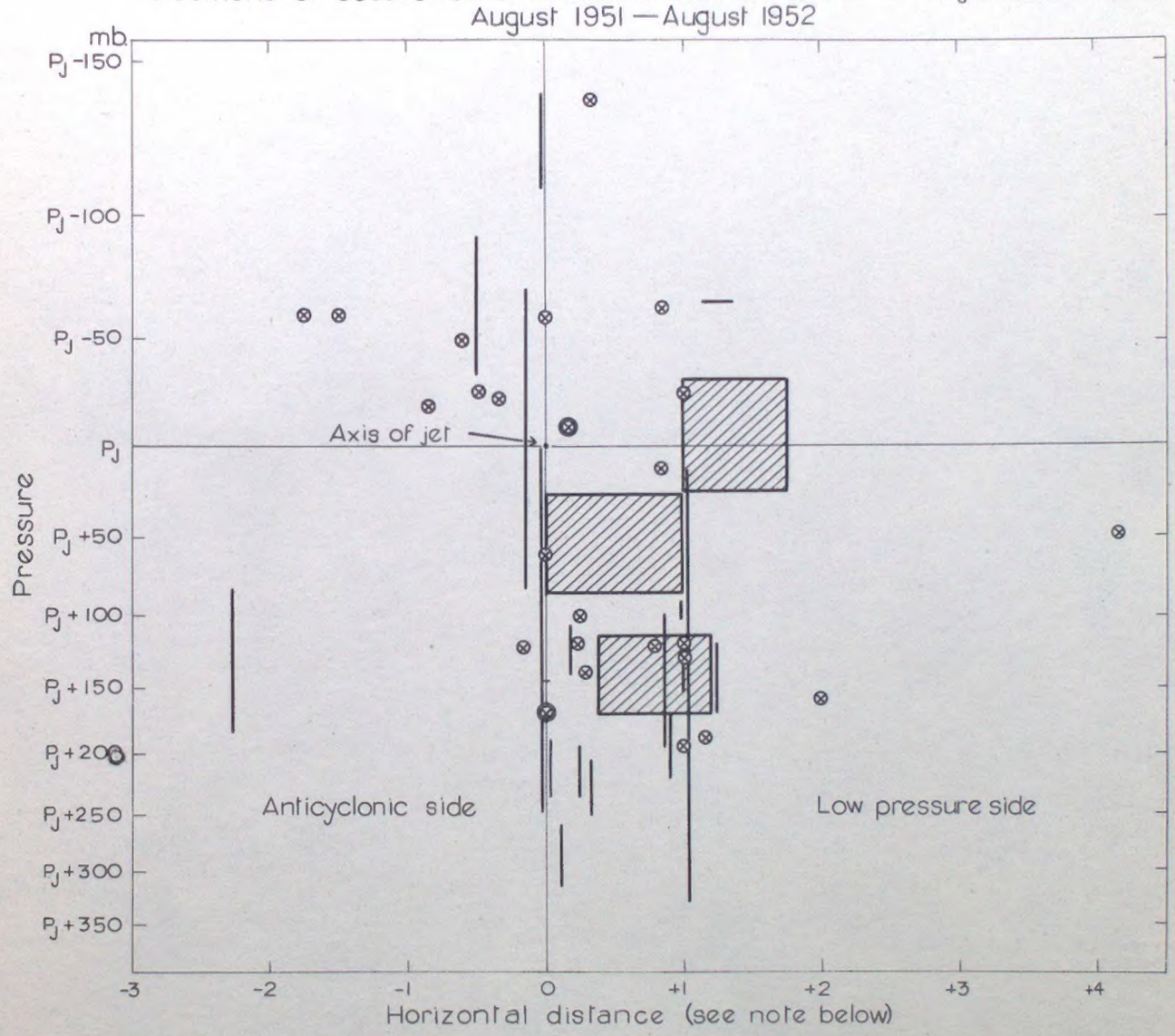
Little or no further progress has been made in this investigation towards formulating any rigid rules to assist the practical forecaster in his task of predicting the occurrence of high level turbulence in clear air. Turbulence is a state in which the air undergoes rapid and random local fluctuations and it appears very probable, at this stage, that it is only the statistical properties that can be recognised and subjected to analysis. Recent reports from jet aircraft indicate that severe turbulence can be experienced in practically any weather situation up to a height of at least 48,000 feet and well above the tropopause. But, nevertheless, the results obtained in these investigations should be of some help to the forecaster in recognising the regions of the atmosphere where aircraft flying at speeds of between 250 and 450 knots stand the greater risk of encountering patches of severe bumpiness.

References

1. Bannon, J.K. Severe turbulence encountered by aircraft near jet streams. Met. Mag., London, 80, 1951, p.262.

2. Bannon, J.K. Weather systems associated with some occasions of severe turbulence at high altitude. Met. Mag., London, 81, 1952, p.97.

Fig. 1
Positions of occurence of severe turbulence relative to the jet stream axis
August 1951 — August 1952

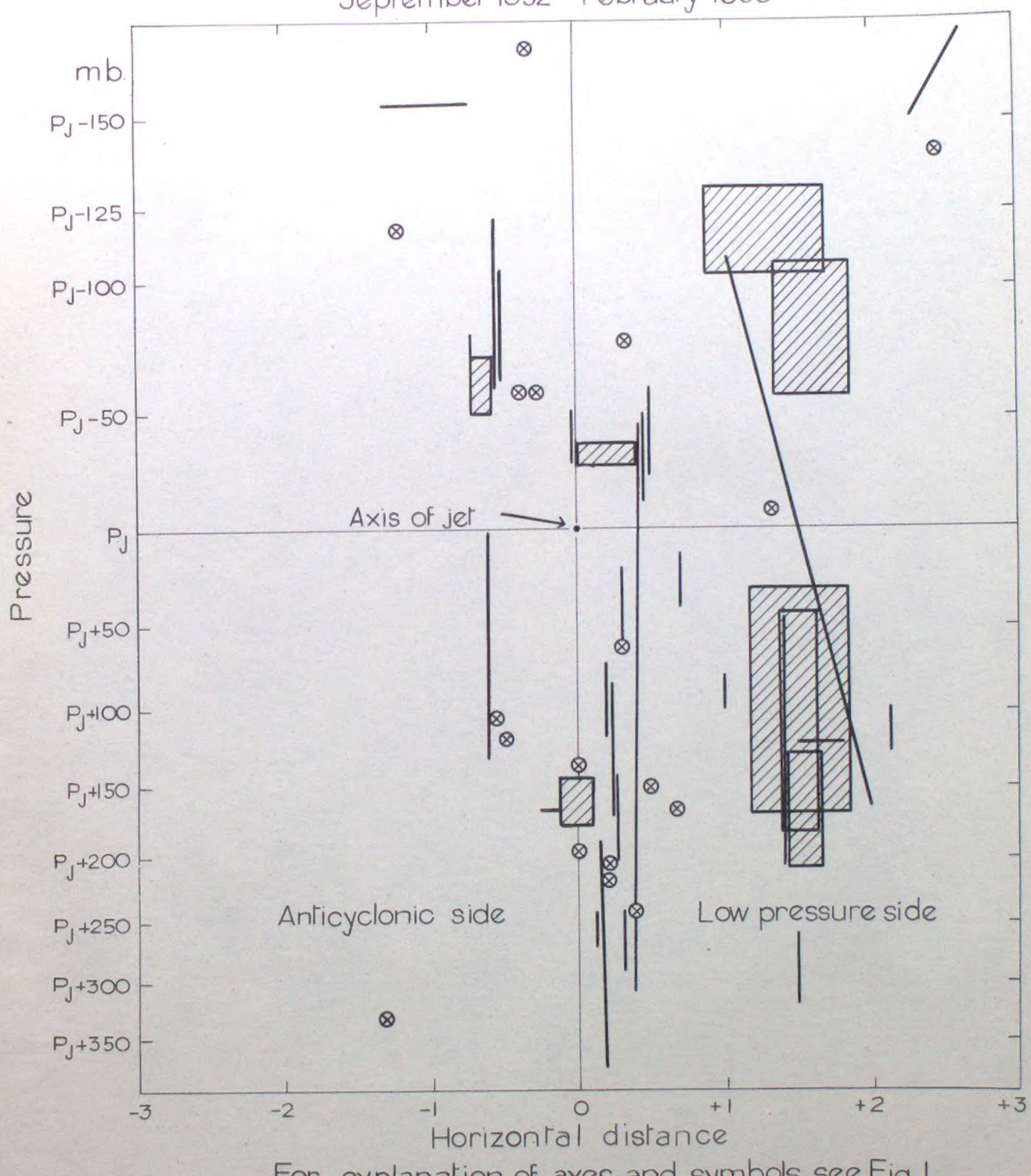


⊗ Isolated observation of turbulence ⊗ More than one observation of turbulence
▨ Zone of observed turbulence — Observation of turbulence along a line

P_J is the pressure at the axis of the jet

Note:- The unit of horizontal distance is the distance on the low pressure side of the jet axis in which the wind speed falls to half its maximum value

Fig. 2
Positions of occurence of severe turbulence relative to the jet stream axis
September 1952 – February 1953



For explanation of axes and symbols see Fig. 1